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Spatio-temporal distribution of the peach fruit fly, *Bactrocera zonata* (Diptera: Tephritidae) infesting citrus orchards at Sargodha, Pakistan

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Abstract: 【Aim】This study was conducted to monitor the population changes of most dominant species of the peach fruit fly, *Bactrocera zonata* distributed at seven localities (Sargodha-Ⅰ, Sargodha-Ⅱ, Bhagtanwala, Sakessar, Chak# 75-SB, Chak# 46-SB and Chak# 104-NB) of Tehsil Sargodha from 2009 to 2011.【Methods】Population occurrence of *B. zonata* was recorded on weekly basis using methyl eugenol pheromone traps charged at fortnight intervals.【Results】The results revealed that the highest population abundance of *B. zonata* was recorded at Sargodha-Ⅰ (53.67, 45.82 and 45.47 flies/trap) followed by Sakessar (41.13, 33.87 and 35.75 flies/trap) whereas Chak# 75-SB had the lowest population occurrence (15.78, 19.18 and 19.15 flies/trap) during all the three years (2009 – 2011), respectively. The highest peaks were observed during April (76.08, 71.94 and 61.51 flies/trap, respectively) followed by May (60.74, 52.63 and 64.00 flies/trap, respectively) and the lowest during February and October each year. Moreover, there were strong positive relationships between the maximum and minimum temperature and *B. zonata* population abundance where negative association was observed for the relative humidity and rainfall. Similarly regression coefficient demonstrated that the maximum temperature was the major contributing factor influencing *B. zonata* population occurrence and rainfall contributed the lowest share.【Conclusion】Regular inspection of *B. zonata* population should be carried out throughout the year, especially when temperature started to rise in April – May as weather factors greatly influence population counts of *B. zonata*.

Key words: Tephritidae; *Bactrocera zonata*; population dynamics; weather factors; citrus; pheromone trap

1 INTRODUCTION

Pakistan having 2.1 million tons of production is the sixth largest producer of mandarin and oranges in the world. Among all countries, Pakistan shares 0.9% and 3.6% value and volume of mandarin and oranges, respectively. With respect to very famous variety of citrus, *Citrus reticulata*, locally known as "Kinnow" Pakistan stands the first for its production in the world. Approximately 95% kinnow is produced in Pakistan, of which District Sargodha contributes to about 70% of total kinnow production and average yield of kinnow per hectare is nine tons which is lower than some developed countries (Anonymous, 2012). Citrus is frequently attacked by a variety of pests such as citrus psylla, citrus leaf miner, lemon butterfly, fruit fly, *etc*. Fruit fly was not a serious pest of citrus before some years because of its thick skin and rind oil, which can kill eggs and larvae but now due to farmers' negligence and poor quarantine policies, fruit fly has become a major threat in citrus growing areas of Pakistan during recent years. Citrus orchards are heavily infested by the attack of fruit fly and estimated fruit losses due to fruit fly at farm level in particular areas are 18% (mango), 30% – 35% (guava), 25% – 35% (melons) and 6% – 11% (citrus). Losses may vary from few percent to 100% depending on severity of the pest (Hardy and Jessup, 2012). About 80% fruit loss has been recorded where citrus and mango

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or guava are grown adjacent to each other (Syed, 1970). Fruit flies belonging to family Tephritidae are of major importance attacking citrus, guava, mango and peach in Pakistan. Tephritid flies comprise of more than 4 000 species which are severe pest of different fruits (Fletcher, 1987). About 11 species of fruit flies have been recorded from Pakistan. Among these, the peach fruit fly (*Bactrocera zonata*) and the oriental fruit fly (*B. dorsalis*) are the dominant species. *B. zonata*, mainly found in plains and *B. dorsalis* in hilly areas (Syed, 1970; Fletcher, 1987; Abdullah and Latif, 2001; Abdullah *et al.*, 2002; Stonehouse *et al.*, 2002). But *B. zonata* is considered as the major problem in guava, mango and citrus orchards in Pakistan (Hashem *et al.*, 2001). It was first originated in South and South-East Asia (Agarwal and Kumar, 1999), and spread to other parts of the world. *B. zonata* has been recorded on 50 types of plant species but it prefers plants with fleshy fruits such as guava, mango, peach, apricot, fig and citrus (White and Elson-Harris, 1992; EPPO, 2002; Ghanim, 2009).

Fruit fly management had been a case of prime importance for Pakistani farmers as majority of the farmers are not innovative. Various locally adopted practices have been tried in the past to combat with this pest but no complete success has been achieved. Farmers mainly prefer chemical control as cover spray as most important measure against fruit flies in Pakistan. These cover sprays are being extensively used against fruit flies in Pakistan (Stonehouse *et al.*, 1998). Malathion, carbaryl, spinosad, imadacloprid, thiacloprid, carbaryl, azinphosmethyl and diptrex have been applied in bait as well as cover sprays. The heavy infestation has led to the use of cover sprays without bait application (Alston, 2002; El-Aw *et al.*, 2008). One simple way to control fruit fly is through pheromone traps containing methyl eugenol as lure. But this technique only attracts male fruit flies and females are left un-attended (Qureshi *et al.*, 1991; Afzal and Javed, 2001; Dhillon *et al.*, 2005).

Reproduction, survival and population pattern of an insect are influenced by a number of environmental factors such as temperature, day length, humidity, rainfall, *etc.* (Ali *et al.*, 2016a, 2016b). Temperature influences fecundity and oviposition behavior of insects (Cammell and Knight, 1992). In most cases, rainfall tends to negatively impact eggs or immature of insects by dislocating or killing them (Kadam and Khaire, 1995). Similarly, humidity exerts direct impact on the coloration of insects (Schmutterer, 1990). Weather factors also influence population changes of *B. zonata*. Temperature, rainfall, humidity, wind speed and wind direction are key factors, thus modifying fruit fly population dynamics (Solangi *et al.*, 2014).

B. zonata population varies in different ecological zones of Pakistan depending upon the climatic conditions. District Sargodha has warm and humid climate. Current studies were conducted to monitor the population occurrence of *B. zonata* and to evaluate the impact of weather factors on population counts by tapping adult males of *B. zonata* through male annihilation technique in seven localities of Sargodha for three consecutive years.

2 MATERIALS AND METHODS

2.1 Study sites

The experiment was conducted at Tehsil Sargodha by covering almost 74 000 acre area. Tehsil Sargodha was divided into seven Markez' (zones), *viz.* Sargodha-Ⅰ (32°3′14.8032″N, 72°41′27.7836″E), Sargodha-Ⅱ (32°4′8.616″N, 72°37′28.9344″E), Bhagtanwala (32°3′0.9″N, 72°55′52.4″E), Sakessar (32°26′7.0″N, 72°44′58.5″E), Chak# 75-SB (32°6′31.5828″N, 72°50′47.31″E), Chak # 46-SB (31°52′48.0828″N, 72°46′39.6732″E) and Chak# 104-NB (32°0′45.3816″N, 72°33′29.4948″E).

2.2 Data collection

From each locality, 50 citrus orchards of local farmers were selected for monitoring the population occurrence of *B. zonata* in three consecutive seasons from 2009 to 2011. Experiment was performed in two factorial randomized complete block design with five replications. No special permit was required to install pheromone traps from farming community as *B. zonata* is not an endangered species in this area. In each orchard, five pheromone traps made of plastic jars charged with methyl eugenol lure (Stedec, Pakistan) were installed in one acre. In each orchard, five acre orchard was selected having five replications. Each orchard was considered as one spot comprising of five pheromone traps. Data regarding *B. zonata* population counts (number of flies trapped per trap) were recorded on weekly basis. Pheromone traps were recharged at fortnightly basis. As weather conditions in each locality differ to some extent so weather parameters (maximum temperature, minimum temperature, rainfall and relative humidity) were also measured on weekly basis at observatory of Pakistan Meteorological Department, Sargodha to evaluate any contribution of weather parameters to population changes.

2.3 Statistical analysis

Two-factor factorial ANOVA (year and month as two independent variables whereas locality as dependent variable) was performed to find any significant difference among months throughout study period at 5% level of significance using SPSS v. 10 (SPSS, 1999). Tukey's HSD post hoc test was used if significant differences were observed in ANOVA. Correlation matrix were carried out to check relationship between population (dependent variable) and abiotic factors (independent variables) using XL-Stat (Adinsoft, 2010). Simple linear regression analysis was carried out to know the impact of abiotic factors on the population fluctuation of *B. zonata* by plotting abiotic factors (independent variables) against *B. zonata* population (dependent variable) for each locality and on cumulative basis using MS Excel 2010.

3 RESULTS

3.1 Population occurrence of *B. zonata* at different localities

Results pertaining to monthly population fluctuation of *B. zonata* revealed that the highly significant variation was observed at Sargodha-Ⅰ ($F = 31.10$, $P < 0.05$) throughout all study years (Table 1). The maximum peak of *B. zonata* was recorded during May, 2009 (140.20 flies/trap) followed by May, 2010 (119.20 flies/trap) and May, 2011 (117.00 flies/trap). The lowest population was observed during October, 2009, October, 2011, and February, 2009 (1.60, 3.60 and 6.00 flies/trap, respectively). During 2010, the lowest peak was observed in October (6.20 flies/trap). During study period, population first started to increase from February to May and then declined until October (Table 2). Sargodha-Ⅱ also showed highly significant difference in *B. zonata* population for three consecutive years ($F = 29.47$, $P < 0.05$). Table 2 demonstrated the population trend of Sargodha-Ⅱ which revealed that much lower population than Sargodha-Ⅰ was observed. In Sargodha-Ⅱ, the maximum population reached to 75.20 flies/traps during April, 2009, followed by 65.80 and 58.20 flies/trap during May, 2010 and May, 2011, respectively. The three lowest peaks were observed during 2010 in February (6.80 flies/trap), June (4.00 flies/trap) and July (5.60 flies/trap). The lowest peak during 2009 and 2011 was observed in February (15.00 and 10.60 flies/trap, respectively). This drastic change in population fluctuation of the two localities showed that population varied significantly at each locality despite of very little difference in weather conditions.

Table 1 Analysis of variance of the data regarding *Bactrocera zonata* population counts at different localities of Tehsil Sargodha

Location	SOV	*df*	*MS*	*F*
Sargodha-Ⅰ	Replication	4	18.90	
	Year	2	800.60	20.33*
	Month	8	22 775.20	578.44**
	Year × Month	16	1 224.50	31.10**
	Error	104	39.40	
	Total	134		
Sargodha-Ⅱ	Replication	4	27.25	
	Year	2	4 316.72	231.06**
	Month	8	4 521.95	242.04**
	Year × Month	16	550.59	29.47**
	Error	104	18.68	
	Total	134		
Bhagtanwala	Replication	4	8.18	
	Year	2	30.70	1.60^{NS}
	Month	8	8 197.76	427.63**
	Year × Month	16	1 540.46	80.36**
	Error	104	19.17	
	Total	134		
Sakessar	Replication	4	18.40	
	Year	2	639.70	25.56**
	Month	8	13 544.00	541.09**
	Year × Month	16	316.10	12.63**
	Error	104	25.00	
	Total	134		
Chak# 75-SB	Replication	4	21.24	
	Year	2	172.27	26.39**
	Month	8	1 905.64	291.86**
	Year × Month	16	101.95	15.61**
	Error	104	6.53	
	Total	134		
Chak# 46-SB	Replication	4	11.96	
	Year	2	129.16	12.50**
	Month	8	4 043.83	391.52**
	Year × Month	16	55.37	5.36**
	Error	104	10.33	
	Total	134		
Chak# 104-NB	Replication	4	5.25	
	Year	2	481.03	59.04**
	Month	8	3 627.48	445.19**
	Year × Month	16	212.74	26.11**
	Error	104	8.15	
	Total	134		

** Highly significant at 1% level of significance; ^{NS} Non-significant at 5% level of significance. Two-factor factorial RCBD ANOVA was performed to know significance among different treatments.

Table 2 Monthly population counts (flies/trap) (means ± *SE*) of *Bactrocera zonata* infesting citrus orchards at different localities of Tehsil Sargodha

Year	Month	Sargodha-Ⅰ	Sargodha-Ⅱ	Bhagtanwala	Sakessar	Chak# 75-SB	Chak# 46-SB	Chak# 104-NB
2009	February	6.00 ± 0.45 no	15.00 ± 1.30 f – i	21.20 ± 1.43 g – j	12.20 ± 0.37 n – q	9.20 ± 0.66 g – j	14.40 ± 0.98 m – p	20.80 ± 1.07 f – i
	March	35.40 ± 1.03 hij	31.00 ± 1.52 de	31.60 ± 2.01 efg	31.00 ± 1.41 hij	13.80 ± 1.07 efg	44.00 ± 2.37 cde	21.00 ± 1.64 fgh
	April	75.20 ± 3.69 e	75.20 ± 2.92 a	114.20 ± 2.60 a	122.60 ± 6.97 a	43.40 ± 1.47 a	55.80 ± 2.60 ab	46.20 ± 1.66 c
	May	140.20 ± 5.88 a	57.80 ± 2.85 b	50.80 ± 1.20 d	72.80 ± 2.50 d	28.80 ± 2.65 b	42.00 ± 1.41 de	32.80 ± 1.59 d
	June	60.00 ± 2.49 fg	32.40 ± 1.66 d	30.80 ± 1.24 efg	42.40 ± 2.38 fgh	14.60 ± 1.03 efg	29.00 ± 1.14 ghi	24.40 ± 0.81 ef
	July	46.40 ± 2.89 gh	21.40 ± 1.63 ef	19.20 ± 1.39 ij	32.60 ± 1.21 g – j	11.20 ± 0.86 f – i	24.80 ± 1.32 ijk	23.60 ± 1.36 efg
	August	31.20 ± 1.93 i – l	19.00 ± 1.52 fgh	23.40 ± 1.69 f – i	26.60 ± 1.57 i – m	5.80 ± 0.58 hij	15.80 ± 1.07 l – o	11.80 ± 0.73 l – o
	September	70.80 ± 3.38 ef	56.00 ± 2.97 b	11.00 ± 0.71 jk	18.60 ± 1.17 k – p	11.00 ± 0.89 f – i	12.00 ± 0.71 nop	11.40 ± 0.51 l – o
	October	1.60 ± 0.24 o	30.60 ± 2.62 de	7.80 ± 0.58 k	11.40 ± 0.93 n – q	4.20 ± 0.58 j	7.40 ± 0.51 p	6.00 ± 0.71 o
2010	February	7.80 ± 0.86 mno	6.80 ± 1.43 ij	17.20 ± 2.08 ijk	8.60 ± 0.68 opq	4.80 ± 0.37 j	10.80 ± 0.58 nop	14.60 ± 1.03
	March	22.40 ± 2.14 j – m	10.60 ± 2.25 g – j	49.60 ± 2.09 d	37.80 ± 1.71 ghi	19.60 ± 0.87 cde	34.00 ± 1.41 fg	29.20 ± 1.50 de
	April	93.40 ± 5.46 d	65.80 ± 2.22 ab	95.00 ± 4.00 b	97.80 ± 4.32 b	39.40 ± 1.21 a	62.40 ± 2.54 a	49.80 ± 1.74 c
	May	119.20 ± 5.37 b	10.60 ± 1.36 g – j	38.00 ± 1.58 e	61.60 ± 3.46 de	32.00 ± 1.84 b	48.80 ± 2.46 bcd	58.20 ± 1.59 b
	June	33.00 ± 2.12 h – l	5.60 ± 0.93 ij	18.40 ± 1.08 ij	29.40 ± 1.21 i – l	21.20 ± 1.28 c	29.80 ± 1.77 ghi	13.80 ± 0.86 j – n
	July	30.80 ± 1.85 i – l	4.00 ± 0.84 j	11.60 ± 1.08 jk	25.80 ± 1.71 i – m	20.80 ± 1.50 cd	21.00 ± 1.41 j – m	19.40 ± 0.93 f – j
	August	19.80 ± 0.97 k – n	9.00 ± 1.41 hij	18.40 ± 1.21 ij	17.60 ± 0.51 l – p	14.40 ± 1.03 efg	14.20 ± 1.28 m – p	14.00 ± 1.00 i – n
	September	73.00 ± 2.45 ef	40.20 ± 1.46 cd	52.00 ± 1.79 d	22.20 ± 1.24 j – n	14.80 ± 1.02 d – g	17.40 ± 1.36 k – n	11.20 ± 0.80 mno
	October	6.20 ± 0.37 no	10.60 ± 1.21 g – j	20.20 ± 1.66 hij	4.00 ± 1.00 q	5.60 ± 0.51 ij	7.60 ± 0.51 p	12.40 ± 0.93 k – o
2011	February	9.00 ± 0.55 mno	10.60 ± 1.21 g – j	24.00 ± 1.95 f – i	9.20 ± 1.36 opq	5.60 ± 0.51 ij	12.40 ± 0.51	17.20 ± 1.16 g – m
	March	60.20 ± 3.15 efg	19.60 ± 0.81 fg	30.20 ± 2.22 e – h	43.80 ± 1.46 fg	14.80 ± 0.58 d – g	32.80 ± 1.28 gh	31.40 ± 1.29 d
	April	102.80 ± 3.23 cd	43.00 ± 3.08 c	50.80 ± 1.74 d	85.40 ± 2.42 c	31.00 ± 1.52 b	50.60 ± 1.69 bc	67.00 ± 2.59 a
	May	117.00 ± 3.75 bc	58.20 ± 3.01 b	84.00 ± 3.69 c	59.60 ± 1.83 e	39.00 ± 1.64 a	40.80 ± 1.50 ef	49.40 ± 1.44 c
	June	42.40 ± 2.60 hi	30.20 ± 1.59 de	35.00 ± 2.45 e	50.80 ± 1.85 ef	28.60 ± 1.44 b	25.40 ± 1.36 hij	30.40 ± 1.44 de
	July	34.60 ± 2.11 h – k	15.20 ± 1.24 f – i	31.80 ± 1.59 ef	30.00 ± 1.30 ijk	20.80 ± 1.28 cd	22.40 ± 1.08 i – l	19.20 ± 1.07 f – k
	August	18.00 ± 1.22 l – o	11.40 ± 1.50 f – j	22.60 ± 2.77 f – i	15.60 ± 0.51 m – p	16.20 ± 1.11 c – f	14.60 ± 1.03 m – p	15.60 ± 0.51 h – m
	September	15.00 ± 1.58 mno	30.80 ± 2.92 de	16.60 ± 0.93 ijk	20.60 ± 2.14 j – o	11.80 ± 1.16 fgh	12.00 ± 0.95 nop	18.20 ± 1.46 f – l
	October	3.60 ± 0.51 o	14.80 ± 1.39 f – i	11.00 ± 0.71 jk	6.80 ± 0.86 pq	4.60 ± 0.51 j	8.20 ± 0.37 op	8.2 ± 0.37 no

Different letters following the data represent significant difference at 5% level of significance. Means were compared by Tukey's HSD post hoc test when significant differences were observed in ANOVA. Pheromone traps (methyl eugenol lure) were installed to record abundance of *B. zonata* on weekly basis. Pheromone traps were recharged at fortnight intervals. Means ± *SE* with the same letters are not significantly different from each other.

Significant population differences were observed at Bhagtanwala during each year ($F = 80.36$, $P < 0.05$). Population started to appear during February and reached to the highest peak (114.20 flies/trap) during April in 2009. The second highest peak was observed during April, 2010 (95.00 flies/trap) and the 3rd highest peak during May, 2011 (84.00 flies/trap). The lowest peak was recorded during October, 2009 (7.80 flies/trap), followed by September, 2009 (11.00 flies/trap) which was statistically at par during July, 2010 (11.60 flies/trap) and October, 2011 (11.00 flies/trap) (Table 2). *B. zonata* population in Sakessar was found to be statistically significant ($F = 12.63$, $P < 0.05$) during all years. The maximum population was recorded in April, 2009 (122.60 flies/trap), followed by 97.80 flies/trap in April, 2010. The lowest peaks (4.00, 6.80 and 9.20 flies/trap) were observed in October, 2010, October, 2011 and February, 2011, respectively (Table 2). Population trend in Chak # 75-SB was found to be highly significant ($F = 15.61$, $P < 0.05$) among all study years. In this locality, the lowest population was recorded as compared with other localities. Hence, the highest peak reached to 43.40 flies/trap in April, 2009, which was statistically at par with 39.40 and 39.00 flies/trap in April, 2010 and May, 2011, respectively (Table 2). The highly significant variation was observed in *B. zonata* population change among year × month interaction for Chak# 46-SB ($F = 5.36$, $P < 0.05$). The highest peaks were recorded in April during 2010, 2009 and 2011 (62.40, 55.80 and 50.60 flies/trap, respectively) whereas the lowest peaks of 7.40, 7.60 and 8.20 flies/trap were observed during October of 2009, 2010 and 2011, respectively (Table 2). The highly significant variation was observed in *B. zonata* population of Chak# 104-NB ($F = 26.11$, $P < 0.05$). The first highest population appeared during April, 2011 (67.00 flies/trap), significantly different from 58.20 flies/trap during May, 2010. Six and 8.20 flies/trap were the lowest peaks recorded in October during 2009 and 2011, respectively (Table 2).

3.2 Cumulative yearly population occurrence of *B. zonata* at different localities

Fig. 1 demonstrates the yearly population trend of *B. zonata* for all localities of Tehsil Sargodha. The highest population was observed in Sargodha-Ⅰ (53.67, 45.82 and 45.47 flies/trap) during 2009, 2010 and 2011, respectively, followed by Sakessar (41.13, 33.87 and 35.75 flies/trap) and Bhagtanwala (34.44, 35.60 and 34.00 flies/ trap) during 2009 – 2011, respectively. Chak # 75-SB recorded 15.78, 19.18 and 19.15 flies/trap and Chak# 104-NB recorded 22.00, 24.73 and 28.51 flies/trap during 2009, 2010 and 2011, respectively, and were less favored by *B. zonata* as low population trend was recorded in these localities compared to other localities of Tehsil Sargodha.

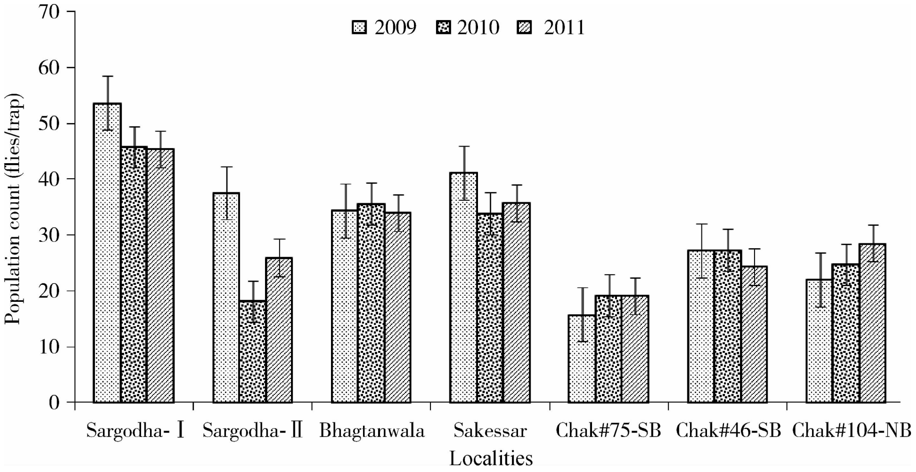

Fig. 1 Cumulative yearly population counts of *Bactrocera zonata* at different localities of Tehsil Sargodha

3.3 Cumulative monthly population occurrence of *B. zonata* during 2009 – 2011

Fig. 2 depicts the cumulative monthly population fluctuation of three years keeping locality as constant. Results showed that the highest peaks appeared during April in 2009 – 2011 (76.09, 71.94 and 61.51 flies/trap, respectively), whereas the lowest peaks were recorded during October of 2009, 2010 and 2011 (12.17, 10.48 and 9.11 flies/trap, respectively).

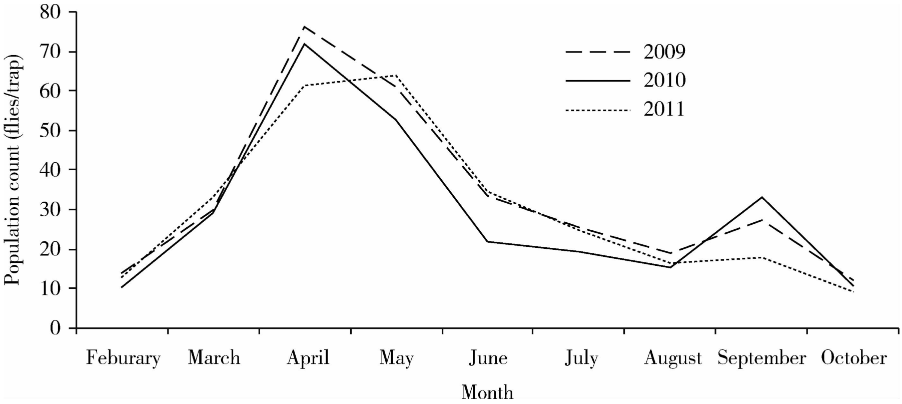

Fig. 2 Cumulative monthly population counts of *Bactrocera zonata* at Tehsil Sargodha during 2009 – 2011

3.4 Relationship between abiotic factors and *B. zonata* population

Table 3 depicts the relationship between abiotic factors and *B. zonata* population at different localities of Tehsil Sargodha. Results showed that a strong positive correlation was observed between *B. zonata* population counts and temperature (maximum and minimum), whereas strong negative association was noticed in case of rainfall and relative humidity. As described in results, significant variation in *B. zonata* population was found among all localities, population data were regressed against abiotic factors (maximum and minimum temperature, relative humidity and rainfall) to evaluate percent contribution of each factor. The results of regression analysis are demonstrated in Fig. 3 (A – H). At Sargodha-Ⅰ, the maximum temperature was major contributing factor ($R^2 = 50.00\%$) followed by the minimum temperature ($R^2 = 41.00\%$) (Fig. 3: A). At Sargodha-Ⅱ, 22.00% variation in *B. zonata* population was shown by the maximum temperature compared to 20.00% variation favored by rainfall (Fig. 3: B). Humidity contributed 34.00% change in population fluctuation of *B. zonata* at Bhagtanwala (Fig. 3: C). At Sakessar, 44.00% and 41.00% variations were caused by the maximum and minimum temperature. Contribution by rainfall was very low (4.00% only) (Fig. 3: D). Similar trend of effect of abiotic factors on population fluctuation of *B. zonata* was observed at Chak # 75-SB, Chak# 46-SB and Chak # 104-NB (Fig. 3: E – G). On cumulative basis, rainfall and relative humidity contributed very low to population variation (R^2 = 8.00% and 22.00%, respectively), whereas the maximum and minimum temperatures were found to be possessing major contribution ($R^2 = 42.00\%$ and 38.00%, respectively) (Fig. 3: H).

Table 3 Correlation coefficient (*r*) between *Bactrocera zonata* population and abiotic factors at different localities of Tehsil Sargodha

Abiotic factors	Sargodha-Ⅰ	Sargodha-Ⅱ	Bhagtanwala	Sakessar	Chak# 75-SB	Chak#46-SB	Chak#104-NB
Temperature (Max.)	0.708**	0.468*	0.460*	0.642**	0.662**	0.657**	0.487*
Temperature (Min.)	0.642**	0.285	0.412*	0.664**	0.648**	0.546**	0.448*
Humidity	−0.453*	−0.38	−0.578**	−0.309	−0.302	−0.226	−0.220
Rainfall	−0.213	−0.443*	−0.416*	−0.202	−0.129	−0.241	−0.182

* Significant at 5% level of significance; ** Highly significant at 1% level of significance.

4 DISCUSSION AND CONCLUSION

Population of *B. zonata* is greatly influenced by variation in abiotic factors. Population pattern of *B. zonata* changes significantly with respect to changes in abiotic factors. Results describing population fluctuation of *B. zonata* demonstrates that the maximum peaks were observed during April and May from 2009 to 2011. The maximum population (140.25 flies/trap) was observed during May, 2009 at Sargodha-Ⅰ, whereas the lowest number of flies was recorded during October, 2011 (3.60 flies/trap) at Sargodha-Ⅰ followed by 4.00 flies/trap during July, 2010 at Sargodha-Ⅱ. Population decline was observed during the second and third year as more flies were trapped in 2009. Markaz-wise population trend shows that *B. zonata* prevailed most at Sarodha-Ⅰ followed by Sakessar whereas citrus orchards of Chak # 75-SB had the lowest population of flies. These results can be compared with findings of Mahmood and Mishkatullah (2007) who worked on the population dynamics of three

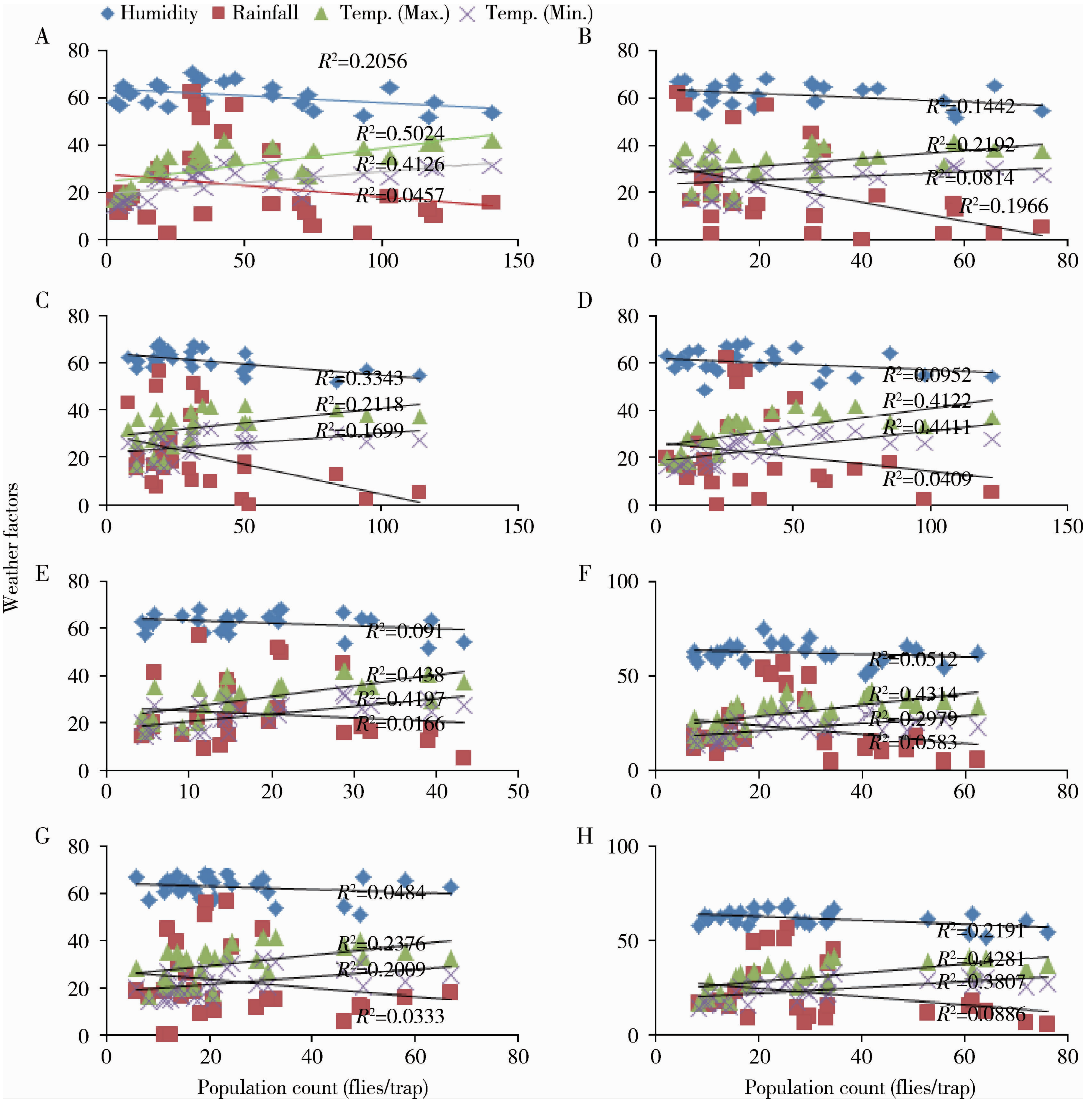

Fig. 3 Coefficient of determination (R^2) values depicting impact of weather factors on the population fluctuation of *Bactrocera zonata* at Sargodha-Ⅰ (A), Sargodha-Ⅱ (B), Bhagtanwala (C), Sakessar (D), Chak# 75-SB (E), Chak# 46-SB (F), Chak# 104-NB (G) and cumulative (H)

species, *B. zonata*, *B. dorsalis* and *B. cucurbitae*, and reported that *B. zonata* population was the lowest from January to February and started to increase with increase in temperature from March to June. With onset of Monsoon season in Pakistan, the highest population peak was observed during August (1 282 flies/trap). Correlation coefficient indicated that strong positive association was observed between temperature and *B. zonata* population. Manzar and Srivastava (2004) supported current findings and reported that May and October favored the highest population of fruit fly in cucurbit fields. In similar context, Babu and Viraktamath (2003) recorded two peaks periods, *i. e.*, one in May and the other in October of fruit flies in mango orchards. Singh *et al*. (2013) also reported that *B. zonata* population attained its highest peak activity in May. Fazlullah *et al*. (2015) monitored *B. zonata* population in peach orchards through different kinds of traps, and concluded that population started to increase during mid-weeks of the season and declined at the end of the season. Contrasting results have been illustrated by Draz (2016) who reported that in Egypt, the highest peaks of *B. zonata* were observed during autumn season (October and November) while during summer and winter seasons, its population remained very low. This difference in population can be attributed to the difference in climatic conditions of the two counties and availability of alternate host plants. Darwish (2012) found that traps received the highest *B. zonata* population during February 2009 and started to decrease from March to June. But during 2010, population was the maximum from February to April and the lowest during September.

Another study by Darwish *et al*. (2014) confirmed our results that *B. zonata* population reached its maximum peak from July to September and declined from the 3rd week of September to the 3rd week of October during 2011. Gupta *et al*. (1990) held the view that the maximum adult activity of *B. zonata* occurred during June on plum and apricot. Dale and Patel (2010) observed the highest peak in September and the lowest peak in May in guava orchards in Gujrat, India. Our results are in contradiction with Sarwar *et al*. (2014) who recorded the highest population of *B. zonata* during October and November (27.83 – 79.58 flies/trap/week) whereas the lowest peak during February (3.00 flies/trap/week) in citrus orchards of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad. The difference in population peaks might be due to difference in weather conditions. *B. zonata* population was monitored in district Kohat, Pakistan for years (2010 – 2011) in guava orchards. The highest population peaks were observed from April to mid of August and declined from end of August to mid of November (Kakar *et al*., 2014). Khan *et al*. (2003a, 2003b) demonstrated the highest peaks from last fortnight of August to first fortnight of September in Sheikhupura, Pakistan. Weekly monitoring of *B. zonata* and *B. dorsalis* were performed by Solangi *et al*. (2014) and concluded that *B. zonata* was the dominant species. The highest catches of 1 211 flies/10 traps were recorded during the 4th week of November whereas the 3rd week of February favored the lowest fly catches (265 flies/10traps). El-Kousy *et al*. (2012) reported that the highest peaks of *B. zonata* were observed in October during 2010 and 2011. These results are in consistent with our findings.

B. zonata populations are greatly influenced by change in weather conditions. Weather parameters mainly temperature and rainfall are the key factors deviating population dynamics of *B. zonata*. Our results clearly revealed that a strong positive association was found between temperature and *B. zonata* population at all seven Markaz' whereas negative relationship was observed for rainfall and relative humidity. Similar findings have been reported by Babu and Viraktamath (2003) and demonstrated that *B. zonata* and *B. correctus* populations had significant relationship with temperature whereas non-significant correlation with relative humidity and rainfall. At Baoshanba, China, air temperature, rainfall, sunlight hours and relative humidity are the major climatic factors that are correlated with changes in the size of the *B. dorsalis* population (Chen and Ye, 2007). Solangi *et al*. (2014) also supported these findings and reported that the correlation between *B. zonata* infestation and temperature was significantly positive ($r = 0.5215^{**}$) which indicates that with increase in temperature, the fruit fly infestation increased considerably. Angood and Sunaid (2012) reported that fruit fly numbers were very low during January and March when temperature remained low.

Citrus fruits are heavily infested by *B. zonata* population and high population has been recorded where citrus-mango-guava orchards are cultivated adjacent to each other. El-Gendy *et al*. (2012) observed that citrus-mango over-cropping pattern showed increased population density of *B. zonata* when compared with citrus orchards alone. Highly significant correlation was observed between *B. zonata* population and citrus-mango orchards. Similarly, Hashem *et al*. (2003) are of the view that pheromone traps kept at citrus-mango over-cropping field attracted the highest number of male flies compared with those in navel-orange.

In conclusion, *B. zonata* remained persistent throughout the study period. The highest population occurrences were recorded when temperature started to increase in April – May. So, management tactics should be planned keeping in mind changing climatic conditions. Regular inspection of *B. zonata* population should be carried out throughout the year as weather factors greatly influence population counts of *B. zonata*.

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巴基斯坦萨戈达地区危害桔园的桃实蝇时空分布

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摘要：【目的】本研究旨在监测 2009 – 2011 年 Tehsil Sargodha 7 个地点(Sargodha-Ⅰ, Sargodha-Ⅱ, Bhagtanwala, Sakessar, Chak# 75-SB, Chak# 46-SB 和 Chak# 104-NB)中桃实蝇 *Bactrocera zonata* 优势种的种群变化情况。【方法】通过甲基丁香酚信息素诱捕器诱捕桃实蝇,每周统计记录桃实蝇种群发生情况,诱捕器每两周加药一次。【结果】结果表明,在调查的 3 年(2009 – 2011)中,Sargodha-Ⅰ的桃实蝇种群多度最高(分别为 53.67, 45.82 和 45.47 头/诱捕器),其次为 Sakessar(分别为 41.13, 33.87 和 35.75 头/诱捕器),而 Chak# 75-SB 的种群多度最低(分别为 15.78, 19.18 和 19.15 头/诱捕器)。每年桃实蝇发生最高峰出现在 4 月(分别为 76.08, 71.94 和 61.51 头/诱捕器),其次为 5 月(分别为 60.74, 52.63 和 64.00 头/诱捕器),而在 2 月和 10 月发生量最低。另外,桃实蝇种群多度与最高和最低气温呈较强的正相关,而与相对湿度和降雨量呈负相关。同样,回归系数表明,最高气温是影响桃实蝇种群发生的主要因素,而降雨量的影响最小。【结论】应当全年对桃实蝇进行定期监测,由于气象因子严重影响桃实蝇的种群发生情况,因此尤其应监测其在 4 – 5 月温度开始上升时的发生情况。

关键词：实蝇科；桃实蝇；种群动态；气象因子；柑橘；信息素诱捕器

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